

# Limits from rapid TeV variability of Mrk 421

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## ABSTRACT

The extreme variability event in the TeV emission of Mrk 421, recently reported by the Whipple team, imposes the tightest limits on the typical size of the TeV emitting regions in Active Galactic Nuclei (AGN). We examine the consequences that this imposes on the bulk Lorentz factor of the emitting plasma and on the radiation fields present in the central region of this Active Nucleus. No strong evidence is found for extreme Lorentz factors. However, energetics arguments suggest that any accretion in Mrk 421 has to take place at small rates, compatible with an advection-dominated regime.

**Key words:** galaxies: active - galaxies : jets - BL Lacertae objects: individual: Mrk 421 - gamma-rays: observations - radiation mechanisms - accretion

## 1 INTRODUCTION

The intense  $\gamma$ -ray emission from radio-loud AGN (and in particular from blazars) argues strongly, independent of other evidence, in favour of the role of relativistic beaming in the physics of this class of source, as proposed almost 20 years ago by Blandford & Rees (1978). In fact, the requirement that the  $\gamma$ -ray source is optically thin to the process of electron-positron ( $e^\pm$ ) pair production, sets strong limits on the comoving radiation density at frequencies above the pair production threshold.

The (potential) target photons can be modelled within the  $\gamma$ -ray emitting region, as well as at all scales along the line of sight, from the very central core of these Active Galaxies to the diffuse background field.

Here we concentrate on the physical constraints that these observations impose within the inner  $\sim$  pc (for considerations relative to the background radiation field see e.g. De Jager, Stecker & Salamon 1994). In particular, we discuss the implications of the recent observation of the large and unprecedented fast variability event in the TeV emission of the BL Lac object Mrk 421 ( $z=0.031$ ) by the Whipple Observatory (Gaidos et al. 1996). On 1996 May 15 the flux above 350 GeV varied by a factor of 20–25 in about 20–30 minutes, with a doubling timescale  $< 15$  min. Note that the whole flare has been observed. This variation sets tight upper limits on the size of the TeV emitting region.

## 2 PAIR OPACITY CONSTRAINTS

The optical depth to  $e^\pm$  pair production by photon-photon interaction,  $\tau_{\gamma-\gamma}$ , for  $\gamma$ -ray photons of energy  $x$  (in units of the electron rest mass energy) is proportional to the compactness of target photons,  $\propto L/R$ , where  $R$  is the length of the path of the  $\gamma$ -ray in the target photon field. More precisely

$$\tau_{\gamma\gamma}(x) \simeq \eta(\alpha)\sigma_T n(x_*)x_*R \quad (1)$$

where  $x_*$  is the energy (in units of  $m_e c^2$ ) of target photons with number density  $n(x_*)$ ,  $\sigma_T$  is the Thomson scattering cross section and  $\eta(1) \sim 0.12$ , where hereafter an energy spectral index  $\alpha \sim 1$  is assumed (Svensson 1987).

### 2.1 Radiation field internal to the $\gamma$ -ray emitting region

Let us consider the limits deriving from any radiation field present in the same region where the TeV photons are produced.

An upper limit to the region size  $r_\gamma$ , implied by the observed  $\gamma$ -ray variability, is  $R = r_\gamma \lesssim ct_{\text{var}}\delta(1+z)^{-1}$ , where  $\delta \equiv (\Gamma - \sqrt{\Gamma^2 - 1} \cos \theta)^{-1}$  is the relativistic Doppler factor of the emitting plasma moving with a Lorentz factor  $\Gamma$  at an angle  $\theta$  with respect to the line of sight and  $t_{\text{var}}$  is the observed variability timescale<sup>†</sup>. We consider the target pho-

<sup>†</sup> Note that the size  $r_\gamma$  is estimated from the  $\gamma$ -ray variability and does not need to assume co-spatial emission with variable flux at other frequencies.

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tons at the threshold energy for pair production, where the cross section is maximum. Taking into account the Doppler transformations of the observed  $\gamma$ -rays, the corresponding target photon frequency is  $\nu_{\text{ir}} \sim 1.2 \times 10^{14} \nu_{\text{TeV}}^{-1} \delta^2$  Hz, with  $\nu_{\text{TeV}} \simeq 1.2 \times 10^{26}$  Hz (corresponding to an energy of 0.5 TeV). The condition of transparency for the TeV  $\gamma$ -rays,  $\tau_{\gamma\gamma} \lesssim 1$ , then translates into a limit on the radiation field at  $\nu_{\text{ir}}$ . By assuming that all the observed monochromatic flux  $F_{\text{obs}}(\nu_{\text{ir}})$  ( $\text{erg s}^{-1} \text{ cm}^{-2} \text{ Hz}^{-1}$ ) is indeed produced co-spatially with the  $\gamma$ -rays, the constraint imposes a lower limit on the relativistic Doppler amplification (e.g. Dondi & Ghisellini 1995; see also Gaidos et al. 1996), namely

$$\delta \gtrsim 10 F_{\text{obs}}^{1/6}(\nu_{\text{ir}}) t_{\text{var},3}^{-1/6} \quad (2)$$

where the observed values for  $t_{\text{var}} = 1000 t_{\text{var},3}$  s and  $\nu_{\text{ir}} F_{\text{obs}}(\nu_{\text{ir}}) \simeq 4 \times 10^{-11} \text{ erg s}^{-1} \text{ cm}^{-2}$  have been substituted. These correspond to the quiescent state reported by Macomb et al. (1995) (at  $\sim 1.4 \times 10^{14}$  Hz).

A Doppler factor  $\delta \simeq \Gamma \gtrsim 10$  would therefore be required to account for the observed TeV emission if the electron/positron population emitting at TeV energies also emits the observed IR flux. Simultaneous monitoring would be required to establish that (see the results of the 1994 and 1995 multifrequency campaigns, Macomb et al. 1995, Buckley et al. 1996).

## 2.2 External radiation fields

Analogously, one can consider constraints both on and from any (quasi-isotropic) radiation field external to the  $\gamma$ -ray emitting region, whose photons can efficiently interact with the TeV radiation.

To estimate the photon-photon optical depth in this case it is necessary to estimate the compactness of this putative field, over a scale size which corresponds to the distance (from the central compact object) at which the high energy emission takes place. A typical perturbation/shock would naturally form, following a change e.g. in the bulk Lorentz factor  $\Gamma$  of the plasma in the jet, at a distance which depends on the intensity and time profile of the velocity change. For a variation  $\Delta\Gamma \sim \Gamma$  occurring over the typical timescale associated with the dimension  $r_s$  of the compact object where the jet presumably forms ( $r_s$  is the black hole Schwarzschild radius), a shock would develop at a distance  $R = R_\gamma \sim r_s \Gamma^2 (1+z)^{-1}$ <sup>‡</sup>. Note that there is a minimum characteristic timescale for AGN variability, which is given by the light crossing time of the compact object  $\sim r_s/c$ , and if we assume the observed  $\gamma$ -ray variability does indeed correspond to this minimum timescale, then the  $\gamma$ -ray emitting region would be located at  $R_\gamma \sim c t_{\text{var}} \Gamma^2 (1+z)^{-1}$ . In other words, if the base of the jet varies on  $\sim r_s/c$ , so would the observed  $\gamma$ -rays, though the scale they come from is  $\sim \Gamma^2 r_s$ .

<sup>‡</sup> Here for simplicity it is assumed that the Lorentz factors of the bulk flow and of the front of any perturbation coincide, as we do not expect that the two values of  $\Gamma$  could differ significantly - for the purpose of this work - unless the shock front moves at extremely relativistic speeds relative to the mean flow.

### 2.2.1 Infrared field

If one simply assumes that a diffuse IR radiation field is present over scale  $R_\gamma$ , with a total flux of intensity equal to the observed  $F_{\text{obs}}(\nu_{\text{ir}})$ , then the transparency condition imposes again a lower limit on the Lorentz factor (which determines  $R_\gamma$  and therefore the compactness of target photons). This limit corresponds to an extremely high

$$\Gamma \gtrsim 1.2 \times 10^3 F_{\text{obs}}^{1/2}(\nu_{\text{ir}}) t_{\text{var},3}^{-1/2} \quad (3)$$

which in turn implies that the TeV emission is produced at distances of the order of  $R_\gamma \sim 4 \times 10^{19} F_{\text{obs}}(\nu_{\text{ir}}) t_{\text{var},3}^{-1} \text{ cm}$ .

While there is no obvious reason why the plasma cannot propagate with this extreme  $\Gamma$ , the above limit depends on the hypothesis that a photon flux comparable with the observed one pervades the region. One can then reverse the argument, assuming a more ‘traditional’ value of the Lorentz factor, say  $\Gamma \sim 10 \Gamma_1$  (e.g. Ghisellini et al. 1993), and deducing an upper limit on the diffuse IR field. This requires that the external field,  $F_{\text{ext}}(\nu_{\text{ir}})$ ,

$$\left( \frac{R_\gamma}{R_{\text{ir}}} \right) F_{\text{ext}}(\nu_{\text{ir}}) \lesssim 7 \times 10^{-5} F_{\text{obs}}(\nu_{\text{ir}}) \quad (4)$$

which significantly constraints the existence and properties of an IR emitter, e.g. in the form of a dusty torus, in the surrounding of the central object<sup>§</sup>. In terms of luminosity, this corresponds to  $\nu_{\text{ir}} L_{\text{ext}}(\nu_{\text{ir}}) \lesssim 10^{40} \text{ erg s}^{-1}$ , if the IR emitting region is located at distances  $\gtrsim R_\gamma \sim 3 \times 10^{15} t_{\text{var},3} \Gamma_1^2 \text{ cm}$ .

### 2.2.2 Starlight

Within the inner  $\sim \text{pc}$  of the active galaxy, starlight constitutes a further radiation field in the surroundings of the compact object. While it is not possible to exactly quantify its intensity, an order of magnitude estimate, based on the centre of our galaxy, suggests a starlight radiation density corresponding to a luminosity  $L_{\text{star}} \sim 10^{40} \text{ erg s}^{-1}$  within  $R_{\text{star}} \sim 1 \text{ pc}$ , with a spectrum peaking, say, at  $\text{few} \times 10^{14}$  Hz. This radiation however does not contribute significantly to the TeV  $\gamma$ -ray opacity, giving rise to an optical depth of only  $\tau_{\gamma-\gamma}^{\text{star}} \sim 10^{-3} L_{\text{star},40} R_{\text{star},\text{pc}}^{-1}$ .

### 2.2.3 Line emission

Variable emission in weak broad lines have been detected in the spectra of some BL Lac objects (Stickel, Fried & Kühr 1993; Vermeulen et al. 1995; Robinson & Corbett 1996). In particular, Morganti, Ulrich & Tadhunter (1992) report the detection of a broad emission feature in Mrk 421, with a luminosity (in H $\alpha$  and NII) of  $L_{\text{H}\alpha+\text{NII}} \sim 1.5 \times 10^{40} \text{ erg s}^{-1}$ . While during the observation reported by Morganti et al. a broad H $\alpha$  line is not clearly resolved, the detection of this component in the spectra of other BL Lacs would support the hypothesis that in Mrk 421 the reprocessed emission also is produced by high velocity gas, supposedly in a broad line region. By adopting, in analogy with radio-loud quasars (and in fact quite arbitrarily for BL Lacs), a covering factor

<sup>§</sup> In a recent paper Protheroe & Biermann (1997) examine in details the effect of pair opacity above a typical AGN torus.

of  $\sim 10$  per cent and a Thomson optical depth  $\tau_T$  of a scattering diffuse medium of the same order, one can estimate the corresponding (isotropic) intensity of a ionizing radiation field localized within a typical  $R_{\text{BLR}}$ . The compactness of this putative broad line emitting region translates again into a  $\gamma$ -ray optical depth  $\tau_{\gamma-\gamma}^{\text{line}} \sim 2L_{\text{ion},41} R_{\text{BLR},16}^{-1}$ . Also this limit is too weak to set strong constraints either on the ionizing radiation field or the bulk speed of the emitting TeV plasma.

It is worth noticing that the estimate of the photoionizing flux responsible for an observed broad H $\alpha$  line, requires a luminosity of the order of  $10^{40}$  erg s $^{-1}$ , not far from the limit derived in eq. (4).

#### 2.2.4 Disc emission

There is little evidence of the presence of thermal emission contributing to the observed radiation in BL Lac objects, probably the strongest indication being given by the narrow (and possibly broad) line emission. In particular, the limit inferred in eq. (4), under the assumption that the plasma bulk Lorentz factor is  $\Gamma \lesssim 10$ , sets constraints on the emission from any material accreting, in the form of a disc, onto the central black hole. These can be translated into limits on the fundamental parameters regulating the structure and radiative properties of an accretion disc, namely the black hole mass  $M$ , accretion rate  $\dot{M}$  and viscosity.

In view of the numerical complication involved in the self-consistent computation of the emission at IR frequencies for the full range of the parameter space of  $M, \dot{M}$ , viscosity (e.g. Szuszkiewicz, Malkan & Abramowicz 1996 and references therein), we adopt an extremely simplified approach. The emission from the disc can be roughly described (in  $\nu L(\nu)$ ) by a power law (with the standard spectral index  $\sim 1.3$ ), peaking at the energy roughly corresponding to the maximum disc temperature, namely between the optical-UV and the soft-X band and extending to the low energies where the emission from the external radii dominates.

We therefore consider the limits in mass and accretion rate of a disc not exceeding the luminosity of Mrk 421 in the optical-soft X-ray band,  $\nu_{\text{uv}} L_{\text{uv}}$ , and extrapolate the emission from the peak frequency to the IR band as a power law of index 1.3. This extrapolated luminosity is then compared with the limit given by eq. (4).

However it is also necessary to estimate the location (within the limits of the optically thick Keplerian  $\alpha$  disc assumptions, Shakura & Sunyaev 1973), of the IR emitting region,  $R_{\text{ir}}$ . In fact, that allows us: a) to determine self-consistently the solution of the disk equations; b) to check that the IR emitting region is within the outer self-gravitating radius; c) most important, to estimate its location with respect to the  $\gamma$ -ray emitting region. The last point in fact determines the interaction angles (and therefore energies) of the target photons for the TeV  $\gamma$ -rays. In particular, for  $R_{\text{ir}} < R_\gamma$ , we consider that the absorbed IR photons have been mostly scattered and isotropized by an external medium with Thomson optical depth  $\tau_T \sim 0.1\tau_{T,-1}$ . This in turn implies that the IR disc luminosity, consistent with the observed TeV emission, can be up to  $\sim 10$  times the limit derived in eq. (4).

Let us express the mass  $m$  in solar units and the accretion rate in Eddington units,  $\dot{m} \equiv \dot{M}/\dot{M}_E$  (where

$\dot{M}_E = L_E c^{-2}$  and  $L_E$  is the Eddington luminosity). If we require that this bolometric luminosity does not exceed the observed emission  $\nu_{\text{uv}} L(\nu_{\text{uv}})$ , this implies  $\dot{m} m_7 \lesssim 8 \times 10^{-2}$ . By extrapolating from the peak of the energy distribution to IR frequencies, the parameters of a standard thin Keplerian disc are then constrained to  $\dot{m} m_7^2 \lesssim 5 \times 10^{-3} \tau_{T,-1}^{-3/2}$ . In this limit we have taken into account that for typical  $m \gtrsim 10^6$  and  $\dot{m} \lesssim 1$ , the disc radius which dominates the IR emission is smaller than  $R_\gamma$  (where a Lorentz factor  $\Gamma = 10$  has been adopted). For this range of  $m, \dot{m}$ , and a viscosity parameter  $\gtrsim 10^{-5}$ , the disc at  $R_{\text{ir}}$  is not self-gravitating.

Therefore unless either Mrk 421 harbours a black hole of mass  $\lesssim 10^6 M_\odot$  or the Lorentz factor of the  $\gamma$ -ray emitting plasma is  $\Gamma \gg 10$  or the TeV  $\gamma$ -ray emitting region is at much larger distances, we are forced to conclude that the accretion rate in this object has  $\dot{m} \lesssim 10^{-2} - 10^{-3}$ .

On the other hand, observations on VLBI scales lead to estimates of the power emitted in the form of jet kinetic luminosity exceeding  $\sim 10^{46}$  erg s $^{-1}$  (e.g. Celotti, Padovani & Ghisellini 1997), suggesting that indeed Mrk 421 is harboring a much higher mass object. This could be reconciled with the low radiative (quasi-thermal) power if any accreting disc is radiatively inefficient. The deduced limits on  $\dot{m}$  are then consistent with the accretion occurring in the advection-dominated regime.

#### 2.2.5 Conclusions

The constraints derived in this section imply that if a region comparable in size to the TeV production site  $R_\gamma$  is pervaded by a radiation field of intensity comparable with the observed one, then an extremely high bulk Lorentz factor,  $\Gamma \gtrsim 10^3$ , is required in order to overcome the limits from photon-photon opacity.

However, one can easily envisage alternative possibilities which would not set such strong limits on the relativistic motion of the plasma. Namely:

- a) any quasi-isotropic IR field could be produced on scales much larger than  $R_\gamma$ .  $\Gamma \sim 10$  would require  $R_{\text{ir}} \sim 10^4 R_\gamma$  ( $\sim 10^{19} \Gamma_{10}^2 t_{\text{var},3}$  cm).
- b) any isotropic (non-beamed) component is much weaker than the observed luminosity, and a typical  $\Gamma \sim 10$  requires that  $F_{\text{ext}}(\nu_{\text{ir}}) \lesssim 10^{-4} F_{\text{obs}}(\nu_{\text{ir}})$ . This result implies that any disc in the nucleus of Mrk 421 accretes at a rate  $\dot{m} \lesssim 10^{-3}$  for black hole masses  $M \gtrsim 10^7 M_\odot$ .

Finally, radiation of stellar origin and a possible photoionizing continuum do not significantly contribute to the opacity for TeV  $\gamma$ -rays.

### 3 ON THE TEV EMISSION MECHANISM

Let us now briefly consider the implications of the observed variability on the radiation mechanism producing the TeV emission. It is widely (but not universally) believed that the high energy  $\gamma$ -ray component in the spectra of blazars originates from inverse Compton scattering of relativistic electrons/positrons on soft photons (e.g. Sikora 1994 for a review). The origin of this photon field however is still a matter of debate, it could comprise both synchrotron photons (SSC) and an isotropic photon field external to the synchrotron emitting region.

The condition that, in the comoving frame, seed photons of frequency  $\nu_o$  are efficiently scattered to TeV energies in the Thomson regime, implies that  $\Gamma\gamma \gtrsim 2 \times 10^6$  and  $\nu_o \lesssim 2 \times 10^{13}$  Hz, where  $\gamma m_e c^2$  is the energy of the scattering electrons/positrons in the jet frame.

The energy density of photons at  $\nu_o$ , as seen by the emitting plasma, can be estimated as  $U'_{\text{ext}} \sim 3 \times 10^{-2} L_{\text{ext},40} \tau_{\Gamma,-1} \Gamma_1^{-2} t_{\text{var},3}^{-2} \text{ erg cm}^{-3}$  where a typical  $\Gamma \sim 10\Gamma_1$  has been assumed and the dimension corresponding to the distance of the  $\gamma$ -ray emitting region. From the observed luminosity,  $L_{\text{obs}} \sim 2 \times 10^{44} L_{\text{obs},44} \text{ erg s}^{-1}$ , the synchrotron photon energy density is of the order of  $U'_{\text{syn}} \sim 0.6 L_{\text{obs},44} t_{\text{var},3}^{-2} \delta_{10}^{-6} \text{ erg cm}^{-3}$ . Therefore  $U'_{\text{syn}}/U'_{\text{ext}} \sim 20 \delta_{10}^{-4}$  which implies that the scattering of external photons can dominate the SSC emission only for  $\delta \gtrsim 20$ .

Finally, rough equilibrium of the total luminosities emitted by Mrk 421 in the synchrotron and inverse Compton components of the spectrum (peaking in the UV–soft X-ray and  $\gamma$ -ray bands, respectively) implies a similarity of the magnetic and radiation energy densities, if the two radiative components are emitted in the same spatial region and most of the inverse Compton scattering is in the Thomson regime. This requires typical magnetic fields of the order of a few Gauss.

#### 4 SUMMARY AND DISCUSSION

Consequences of the extraordinary variability event detected by Whipple for the physical properties of the emitting plasma and the radiation fields which surround the compact object and the powering of the central black hole in Mrk 421 have been examined.

We find that high ( $\gtrsim 10$ ) or even extreme ( $\gtrsim 10^3$ ) bulk Lorentz factors are required for the source to be transparent to TeV  $\gamma$ -rays, unless the radiation fields within and around the  $\gamma$ -ray emitting region are much lower than inferred from the observed flux.

It should be recalled that BL Lac objects in general show little evidence of strong diffuse/isotropic radiation, and therefore the above considerations are not (yet) evidence for the most extreme values of the Lorentz factor. However we note that due to the weak dependence of the Lorentz factor on the compactness in target photons, we do not expect that such high  $\Gamma$  can be easily derived, at present, by  $\gamma$ -ray variability measures.

Still there are no reasons a priori to exclude such a possibility. Clearly, the beaming angle corresponding to  $\Gamma$  as high as thousands would create serious statistical inconsistencies if these results would be extended to all sources and the effective opening angle of the jet was of the same order. Indeed it is likely that the jet plasma flows within an angle  $\gg 10^{-3} \Gamma_3^{-1}$ . Furthermore, it is reasonable to imagine that jets reach such speeds only in the very inner core and that, in Mrk 421, we are observing the jet virtually aligned with its axis. This possibility would be also consistent with the mild apparent superluminal velocity  $\beta_{\text{app}} c \sim 3.8 c$  observed in the radio components of this source (Zhang & Baath 1990).

One should note that even the weaker of the constraints derived on  $\Gamma$  is significantly higher than typical Lorentz factors in BL Lac objects, as derived from limits on the SSC flux, VLBI radio measurement and statistical arguments

(e.g. Ghisellini et al. 1993). Furthermore for these  $\Gamma$  the TeV emission is likely to be mainly due to SSC.

Finally, we briefly consider the global energetics. We have shown that the assumption of a more ‘traditional’ value of the bulk Lorentz factor implies such stringent limits on the radiation field surrounding the nucleus that any accretion is likely to occur at rates  $\dot{m} \lesssim 10^{-3}$ . Interestingly this is further supported by independent recent findings. In fact, following the ideas proposed by Rees et al. (1982) and Fabian & Rees (1995), it has been suggested (Reynolds et al. 1996a) that M87, the nearby FR I galaxy, and by extension FR I radio galaxies in general, host an active nucleus of very low radiative efficiency as a consequence of the accretion being advection-dominated. Extrapolating this to the plausible beamed counterparts of FR I galaxies, namely BL Lac objects (e.g. Urry & Padovani 1995 for a review), one consequently predicts that these sources also are powered by an advection-dominated flow which is responsible for their low radiative (disk) efficiency. The jet power could then be extracted, analogously to M87, either from the spin energy of the black hole (Blandford & Znajek 1977) or as Poynting-dominated outflow along the system rotation axis of an accretion-powered object (Blandford & Payne 1982). This power could be of the order of  $L_{\text{em}} \sim 10^{43} (a/m_g)^2 B_2^2 M_9^2$ , where  $B_2 \propto \dot{m}_{-3}^{1/2}$  is the equipartition field (e.g. Narayan & Yi 1995),  $\dot{m} = 10^{-3} \dot{m}_{-3}$ ,  $a$  is the specific angular momentum and  $m_g = GM/c^2$  the gravitational radius. ¶

Indeed we note that BL Lacs, and in particular Mrk 421, are hosted in elliptical galaxies, consistently with high values of the black hole mass and the suggestion by the above authors that these systems could be accreting hot interstellar medium quasi-spherically at the (Bondi) accretion rate.

This hypothesis could also be consistent with the lack of much reprocessing gas in their surrounding as well as a low ionization flux (but note earlier comments on broad lines, Sec. 2.2.3). If BL Lacs correspond to the final evolutionary stage of sources accreting through a radiatively efficient geometrically thin disk, this would be in (qualitative) agreement with the redshift distribution of BL Lacs, which is biased to low redshifts.

The jet power deduced above could be compared with that estimated from the density of emitting electrons and the inferred Lorentz factors on VLBI scales, which imply a jet power of about three orders of magnitude higher, strongly suggesting that an high mass black hole lies in the very central nucleus of Mrk 421. The high value of the kinetic jet power can however also be reconciled with luminosities  $\sim 10^{43} \text{ erg s}^{-1}$  if jets of BL Lacs (and FR I) are mainly composed of an  $e^\pm$  plasma, as recently suggested on other grounds (Celotti et al. 1997, Bodo et al. in preparation) and in particular for M87 (Reynolds et al. 1996b).

As it is often the case, some of the possibilities discussed above could be settled when more and higher quality data become available. In particular we emphasize the importance of observations of variability at very high energies, which lead to much stronger physical implications when performed simultaneously with other energy bands.

¶ Note that the modeling of the high energy spectral distribution of BL Lacs favors a rather low magnetic field (in the emitting region) compared to high power sources.

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